Force-based modeling of pedestrian dynamics

Algorithmic steering in bottlenecks

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Mohcine Chraibi

Jülich Supercomputing Centre

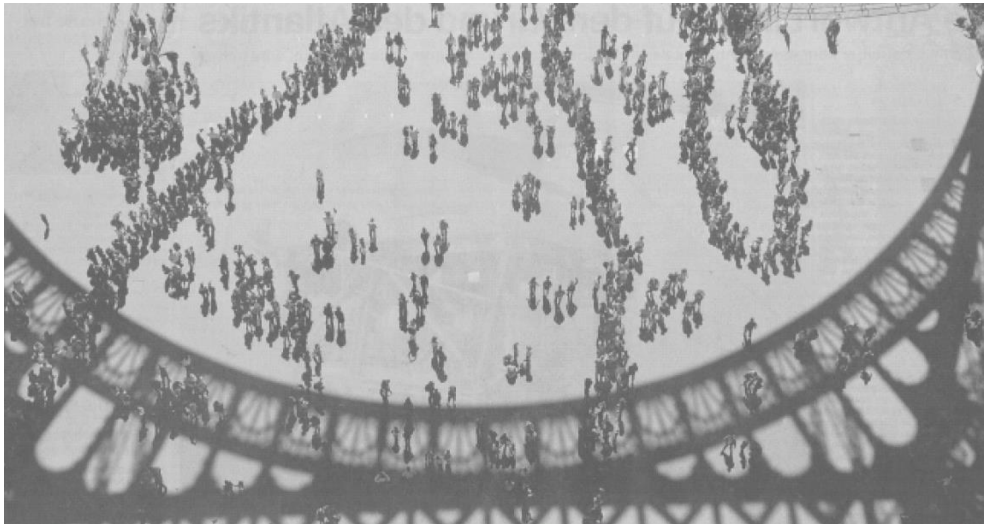
Research Centre Jülich

Outlook

- Motivation and problem statement
- Operational modeling of pedestrian dynamics
- Geometrical representation of pedestrians
- Steering of pedestrians through bottlenecks

Motivation and Problem Statement

Viewpoint of a physicist



- Self-driven particles
  - Pedestrians
  - Vehicles
  - Molecular motors
  - Animals (swarms)
- Interests
  - Transport properties
  - Jams and critical congestions
  - Self organization and collective phenomena
  - …

Interested in the “why-question”

Motivation and Problem Statement

Viewpoint of an engineer

- Aims
  - Design of escape routes
  - Safety at big events
  - Design of transport infrastructures
  - …
- Tools and methods
  - Legal regulations (prescriptive method)
  - Guidelines and handbooks (macroscopic models)
  - Computer simulations (microscopic models)

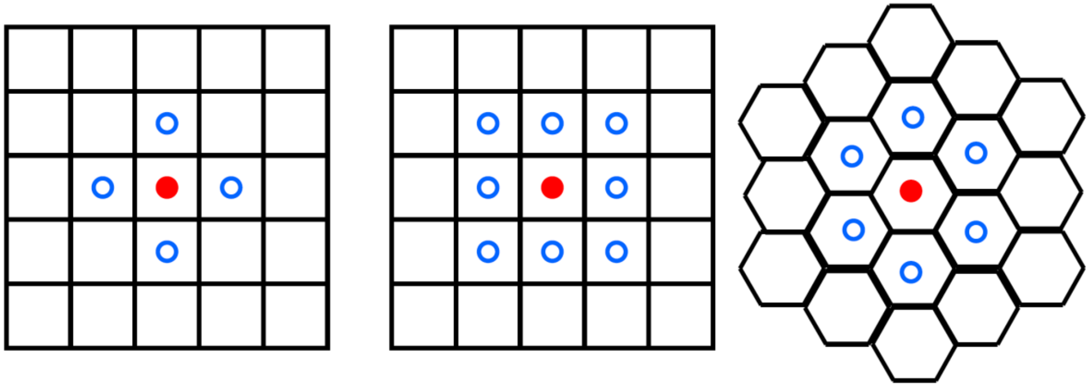
Love parade 2010

Interested in the “what-question” (need numbers)

OPERATIVE MODELING

Cellular automata (Nishinari's talk)

- Discrete in space
- Rule-based
- Fast



Mathematical Modeling of Pedestrian Dynamics

Cellular automata (Nishinari‘s talk)

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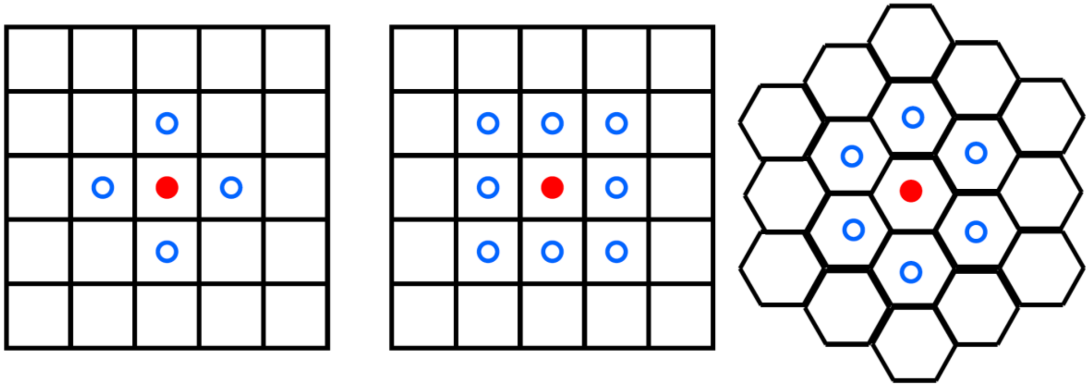
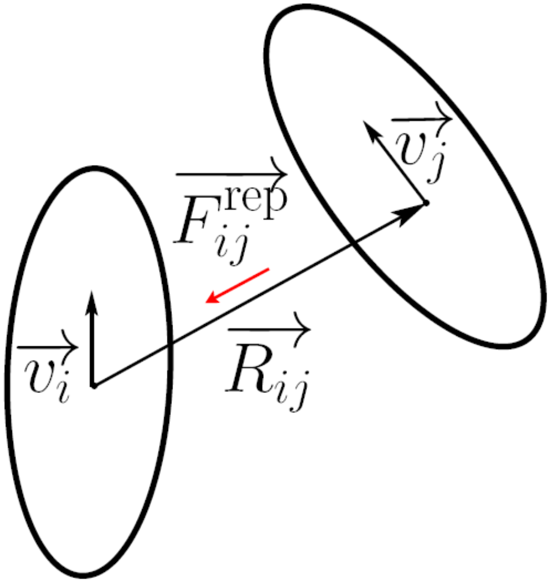


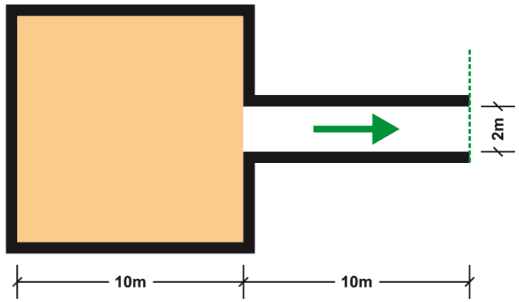
Force-based models

- Continuous in space
- Force-based
- Computationally intensive

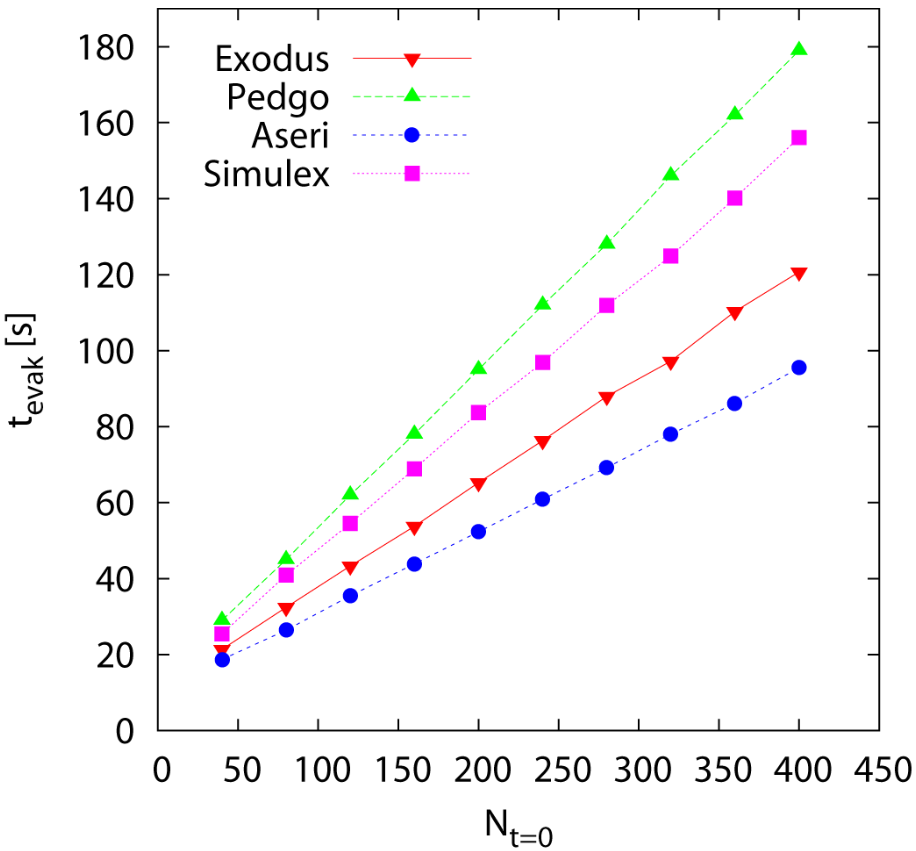


Computer Simulation (State of the Art)

Calculation of evacuation time for a simple room



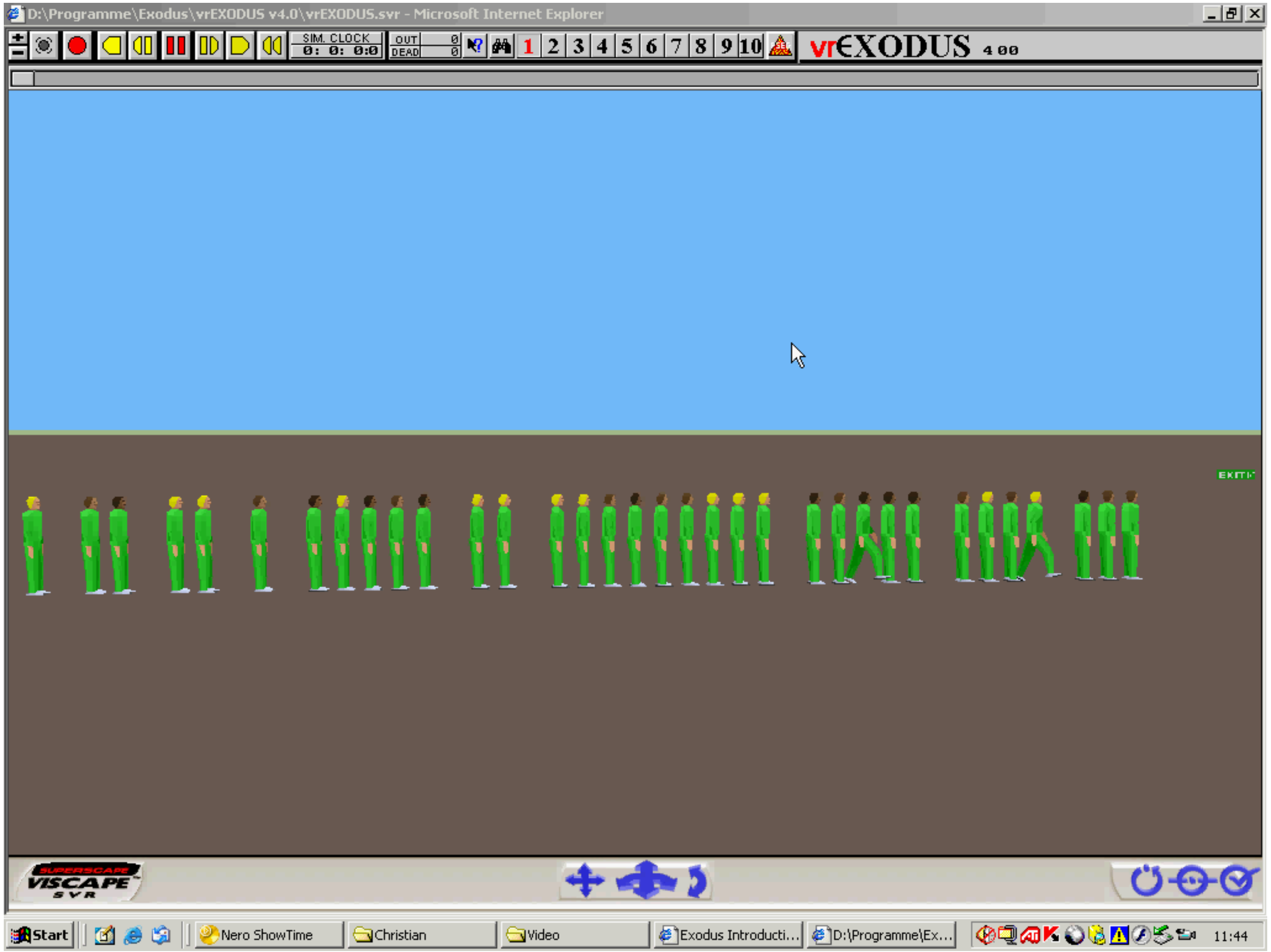
- Test of *Aseri, PedGo, Simulex* and *BuildingExodus* with very simple geometries



Diploma thesis, C. Rogsch, University Wuppertal

Computer Simulation (State of the Art)

How to quantify the “goodness” of a model?



Force-based Models

Equation of motion

$$m_i \ddot{\overrightarrow{R_i}} = \overrightarrow{F_i} = \overrightarrow{F_i^{\mathrm{drv}}} + \sum_{j \in \mathcal{N}_i} \overrightarrow{F_{ij}^{\mathrm{rep}}} + \sum_{w \in \mathcal{W}_i} \overrightarrow{F_{iw}^{\mathrm{rep}}}$$

$$\mathcal{N}_i := \{ j : \| \overrightarrow{R_j} - \overrightarrow{R_i} \| \leq r_c \wedge i \text{ “feels” } j \}$$

$$\mathcal{W}_i := \{ w : \| \overrightarrow{R_{w_i}} - \overrightarrow{R_i} \| \leq r_c \}$$

Parallel update

$$\begin{pmatrix} \overrightarrow{R_i}(t+\Delta t) \\ \overrightarrow{v_i}(t+\Delta t) \end{pmatrix} = \int_t^{t+\Delta t} \begin{pmatrix} \overrightarrow{v_i}(t) \\ \overrightarrow{F_i}(t)/m_i \end{pmatrix} dt + \begin{pmatrix} \overrightarrow{R_i}(t) \\ \overrightarrow{v_i}(t) \end{pmatrix}$$

Force-based Models

Repulsive forces

- Social forces
- Physical forces (contact)
- Attraction forces

Force-based Models

Torque forces

- Social torque
- Contact torque
- Viscous torque
- Attractive torque (?)

Force-based Models

Conflict detection/avoidance

- Rules to manage collisions
- Prohibition of overlapping (tunneling)
  - … by restriction of state of variables

Force-based Models

Complexity-controllability tradeoff

- K. Hirai & K. Tarui, a Simulation of a Crowd in Panic (1975)

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  - Culture
  - Motivation
  - Cooperation/competition

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Force-based Models

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- Human movement is per se complex
  - Culture
  - Motivation
  - Cooperation/competition
- Models tends to be more and more sophisticated … and **uncontrollable**
  - Validation problem

Force-based Models

Example (record of 24 parameters!)

Table 1. Parameters of the modified Helbing-Molnár-Farkas-Vicsek (HMFV) model and their values used in our simulations

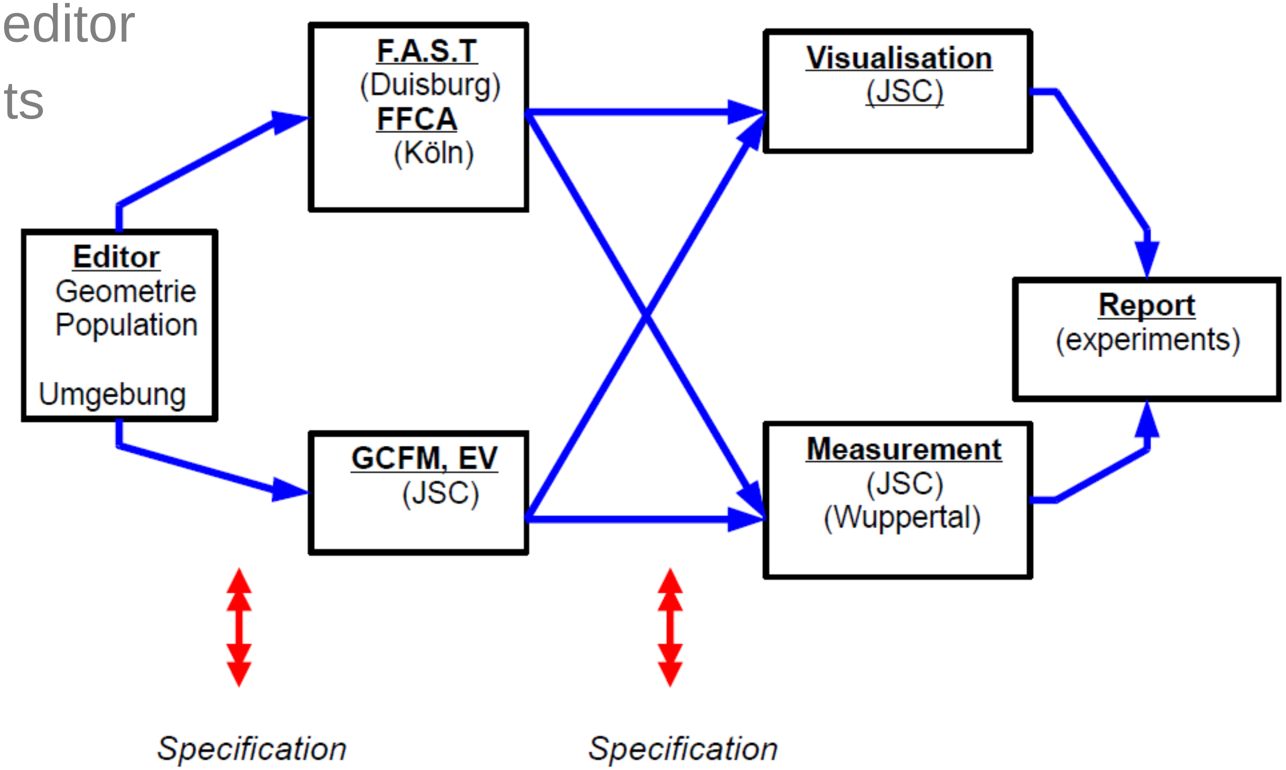
Symbol	Description	Value Used
A_{exit}	Maximum attraction to an exit	$-mv_0/\tau$ (see below)
b	Back/front pedestrian perception ratio	0.3
B	Fall-off length of social repulsive force	0.5 m
B_{exit}	Fall-off length of attraction to exits	15 m
D_0	Diameter of pedestrian	0.7 m
E_m	Maximum of pedestrian excitement factor	1.0
f_{OE}	Force “unsqueezing” pedestrians in the OAE	Four pedestrian weights
F	Magnitude of face-to-face social repulsive	300-900 N
k	Spring constant	$2.4 \cdot 10^4$ kg/sec^2
K_0	“Willingness to wait” factor for face-to-back orientation	0.3
K_1	High-density correction factor for face-to-back orientation	1.2-2.4
K_2	High-density correction factor for face-to-face orientation	1.5
κ	Coefficient of sliding friction	1
m	Pedestrian mass	80 kg
p	Commotion parameter	0
r_i	Radius of pedestrian	0.35 m
$\rho_{\max}$	Maximum pedestrian density	5.4 ped/m^2
$s_{\max}$	Maximum radial squeezing distance	0.07 m
T	Excitement lag time	2 sec
τ	Pedestrian reaction time	0.5 sec
τ_+	Memory learning time	2 sec
τ_-	Memory forgetting time	10 sec
v_0	Pedestrian’s preferred isolated speed	1.5, 3.0, 4.5 m/sec
w_0	Observed isolated pedestrian speed	1.34 m/sec

JUPEDSIM

JuPedSim

www.jupedsim.org

- An open source software for pedestrian dynamics (for **academic** use)
- Two models: CA and GCFM
- CAD to XML editor
- Measurements



Generalized Centrifugal Force Model

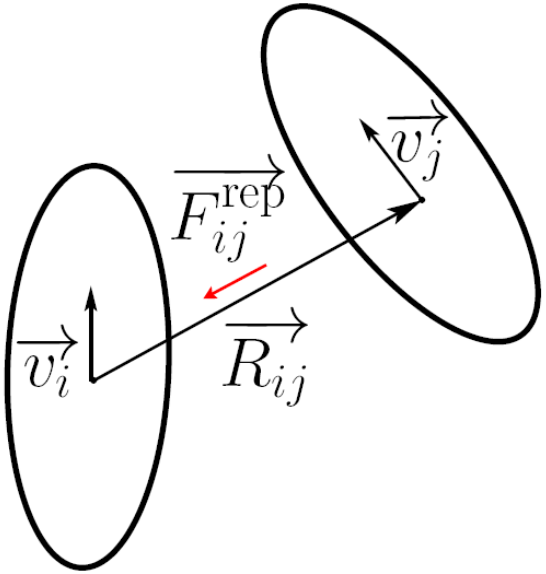
$$m_i \ddot{\overrightarrow{R_i}} = \overrightarrow{F_i} = \overrightarrow{F_i^{\mathrm{drv}}} + \sum_{j \in \mathcal{N}_i} \overrightarrow{F_{ij}^{\mathrm{rep}}} + \sum_{w \in \mathcal{W}_i} \overrightarrow{F_{iw}^{\mathrm{rep}}}$$

Repulsive force

$$\overrightarrow{F_{ij}^{\mathrm{rep}}} = -m_i k_{ij} \frac{(\eta {v_i}^0 + v_{ij})^2}{\mathrm{dist}_{ij}} \overrightarrow{e_{ij}}$$

Driving force

$$\overrightarrow{F_i^{\mathrm{drv}}} = m_i \frac{\overrightarrow{v_i^0} - \overrightarrow{v_i}}{\tau}$$



Chraibi et al. Phys. Rev. E, **2010**, 82, 046111

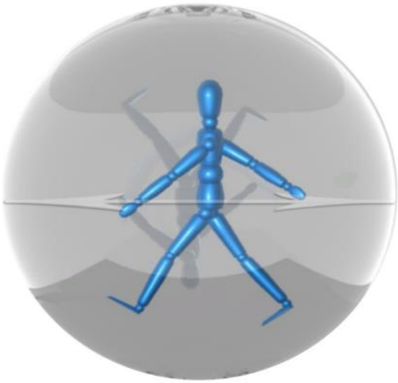
Goals

- Quantitative description of different scenarios
- with one set of parameters
- Small number of parameters (Occam’s razor)
- No restriction on the state variables
- No “collision detection techniques”

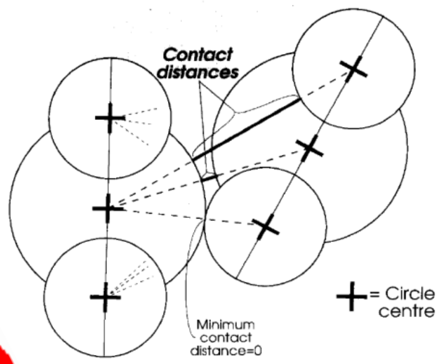
GETTING IN SHAPE

Projection of the Body on 2D Space

Commonly used shapes

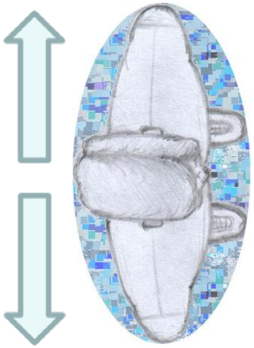


- **Point**
- **Circle**
- **3-Circle**
- **Spheropolygon (Alonso‘s talk)**
  - **(cows)**

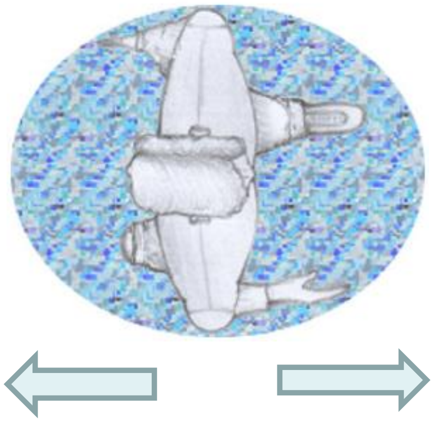


“Body Ellipse”

- Slow pedestrians sway and require space laterally

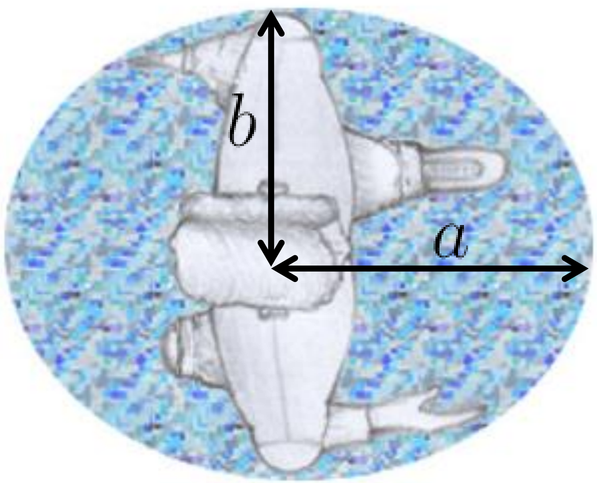


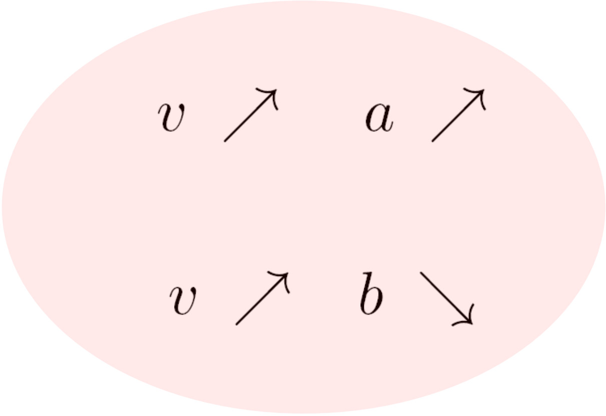
- Fast pedestrians require space in the direction of motion



Pedestrians Get in “Shape”

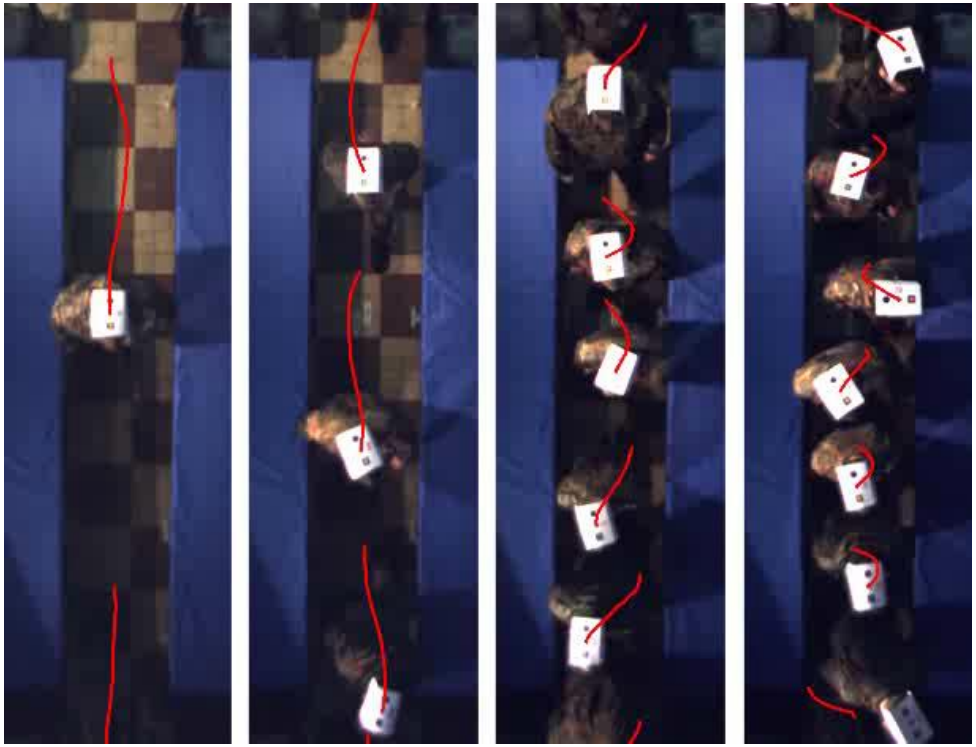
Velocity-dependent semi-axes





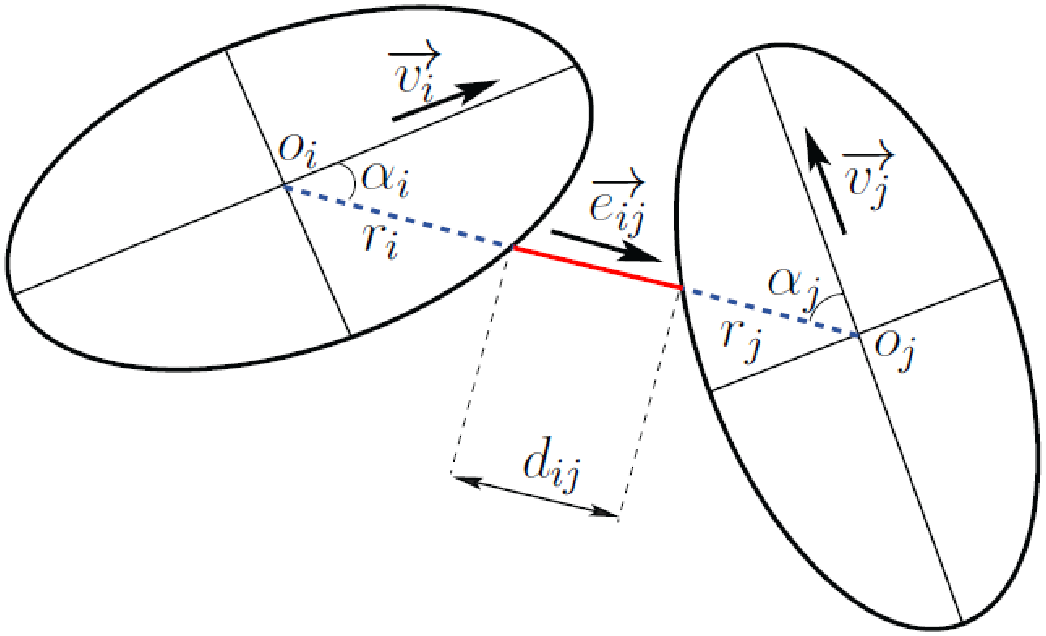
$$a = a_{\mathrm{min}} + \tau_a v_i$$

$$b = b_{\mathrm{max}} - (b_{\mathrm{max}} - b_{\mathrm{min}})\frac{v_i}{v_i^0}$$



Elliptical Shape

Quantities of interest



Elliptical Shape

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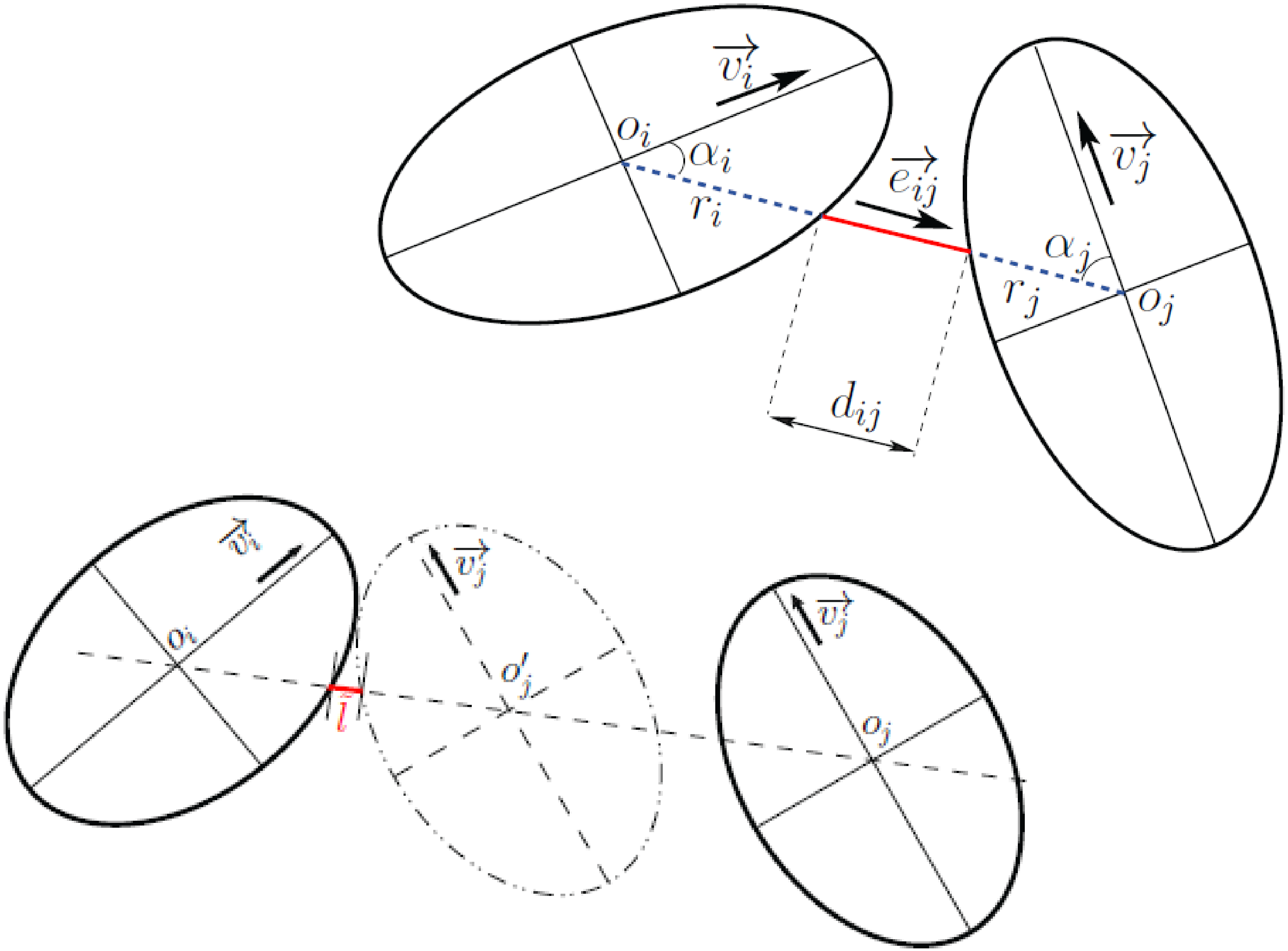
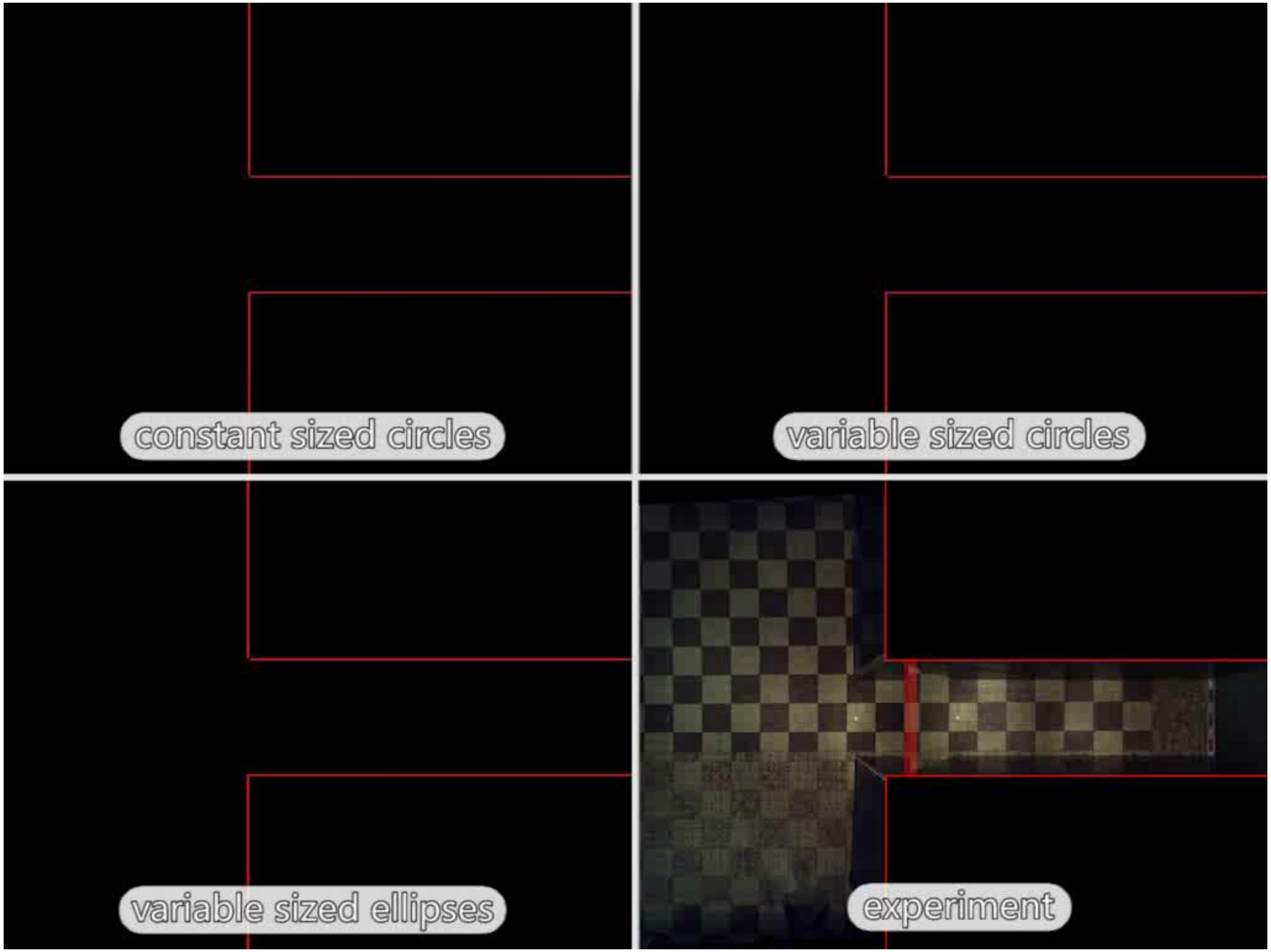


Comparison of Different Shapes



Advantages of Elliptical Shape

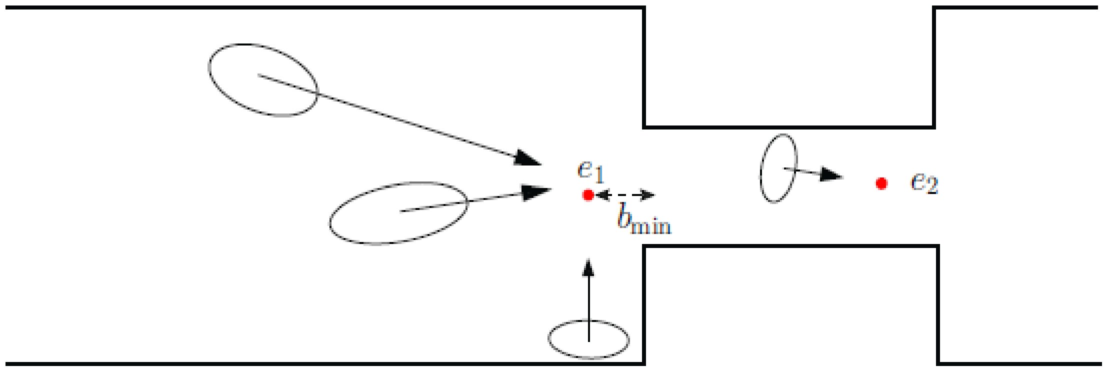
- Simple design
- Approximate fairly well space requirement of humans
- Simplification of the modeling: Turning

PART 3: STEERING

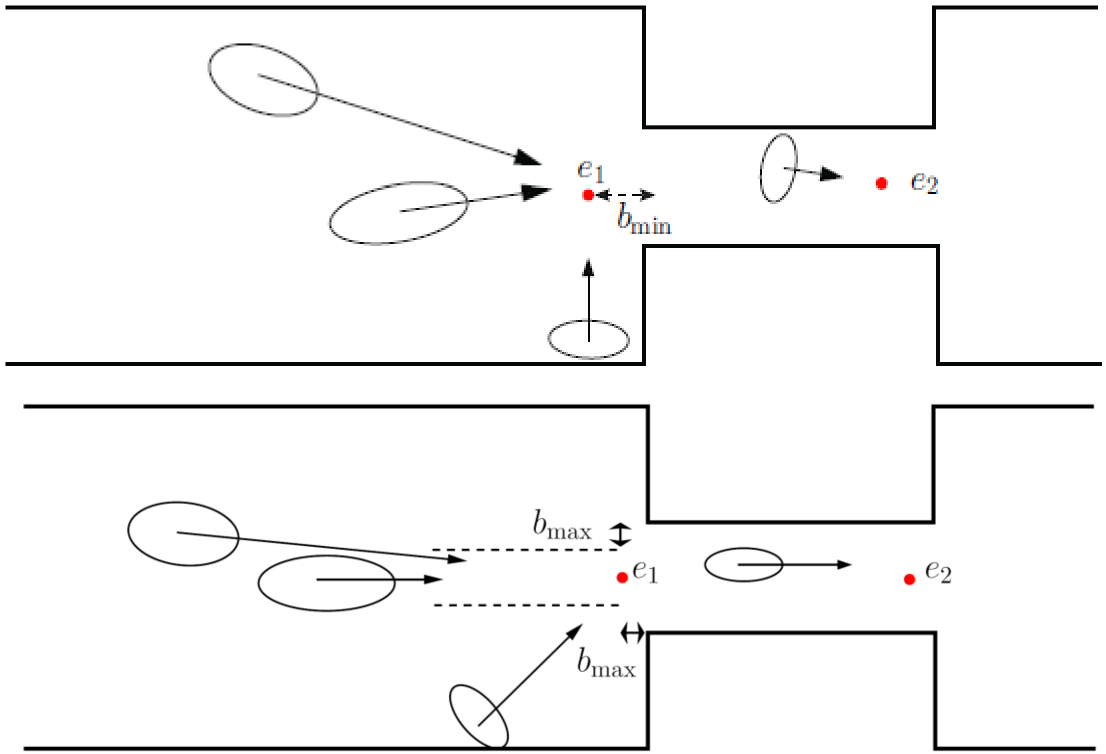
Modeling the Desired Direction

$$\overrightarrow{F_i^{\mathrm{drv}}} = m_i \frac{\overrightarrow{v_i^0} - \overrightarrow{v_i}}{\tau}$$

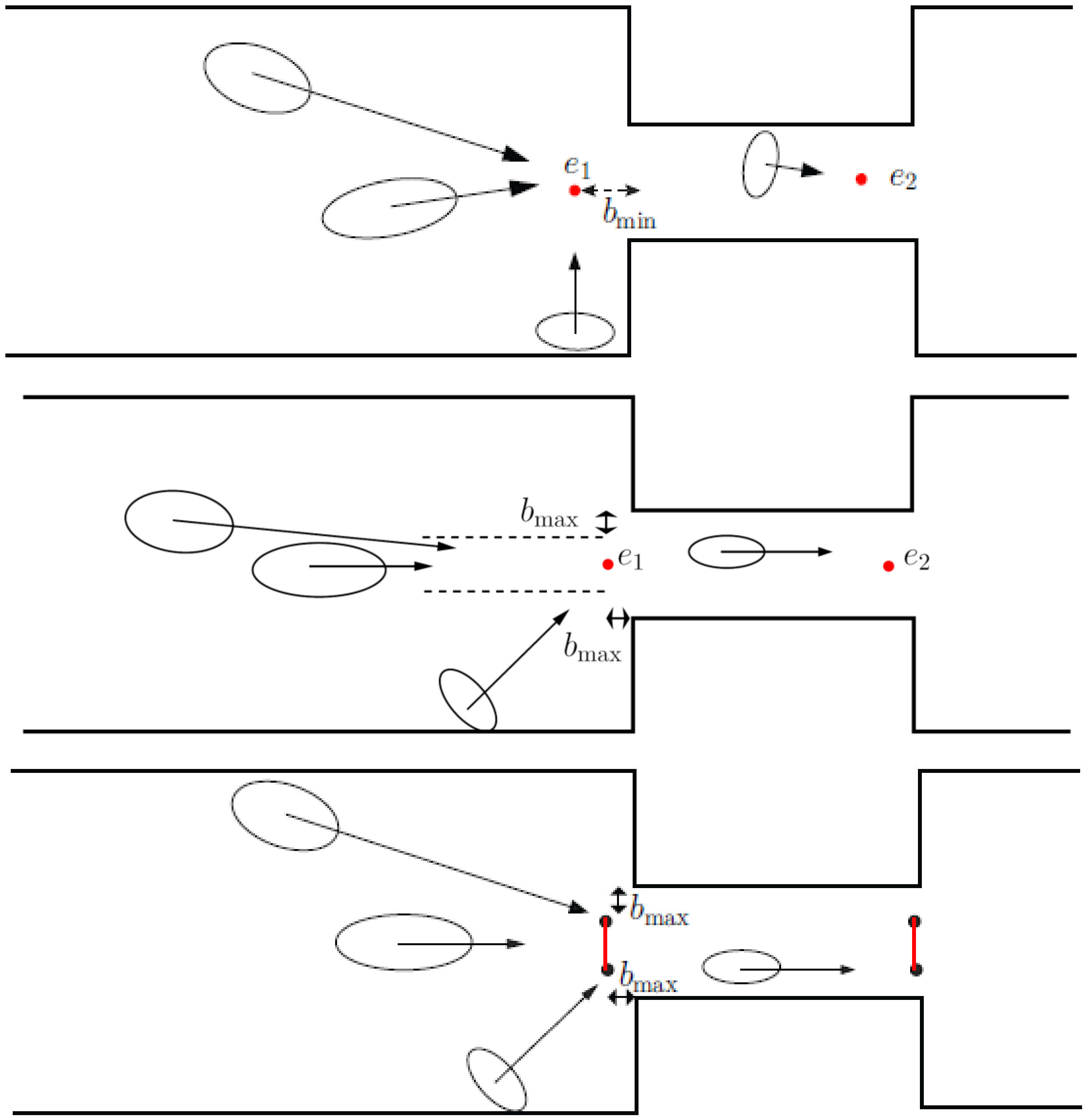
Modeling the Desired Direction



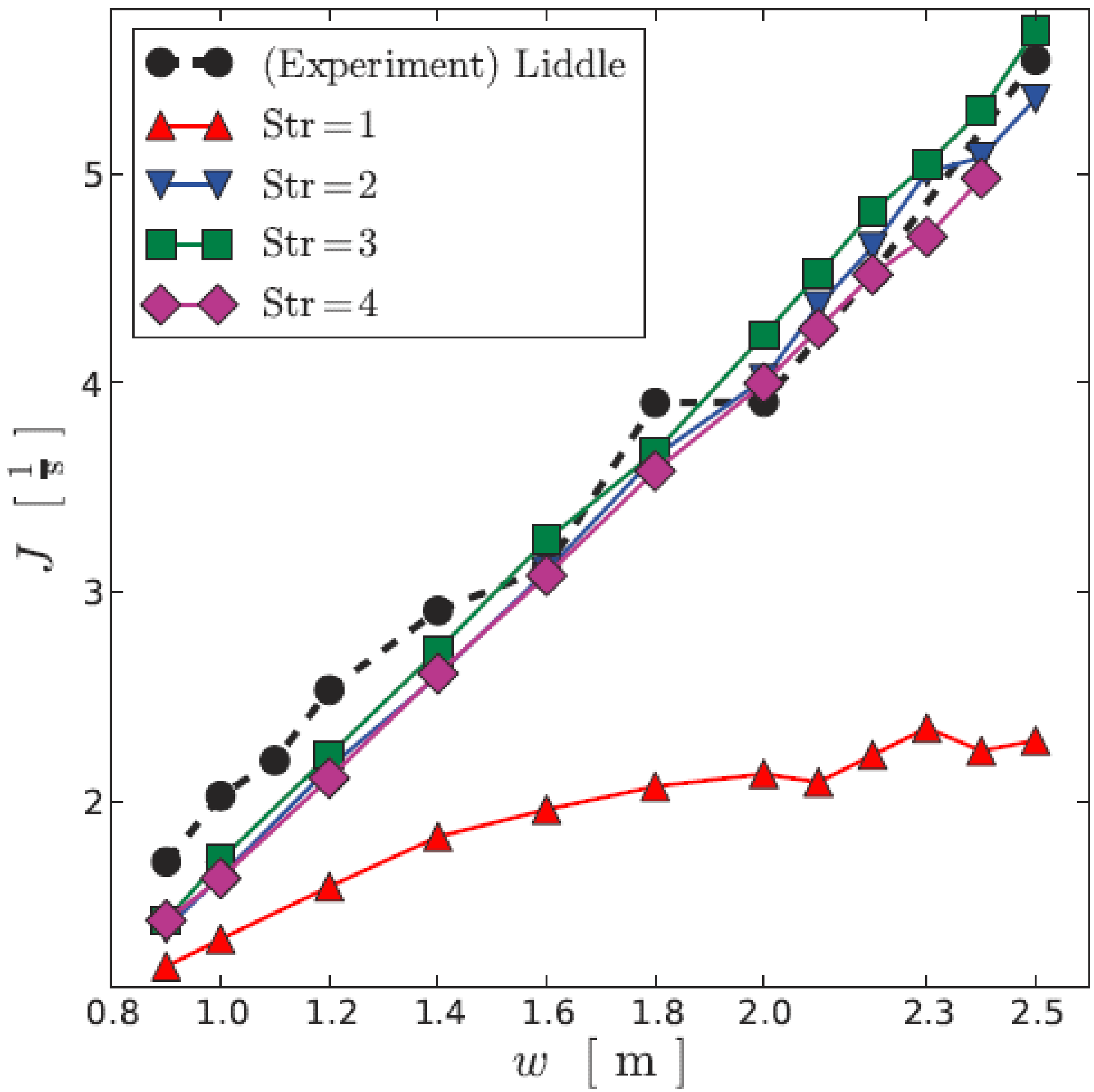
Modeling the Desired Direction



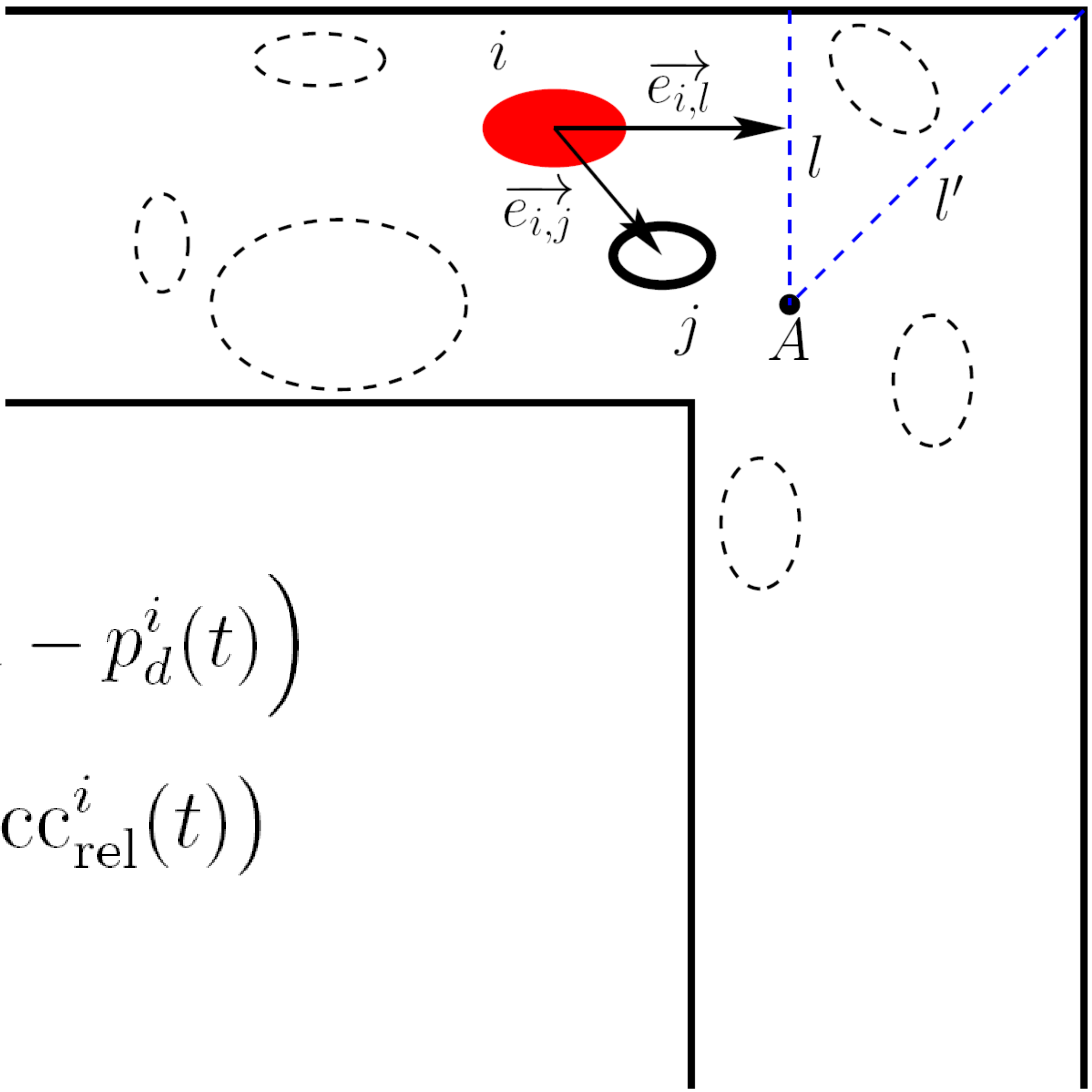
Modeling the Desired Direction



Influence of the Used Strategy



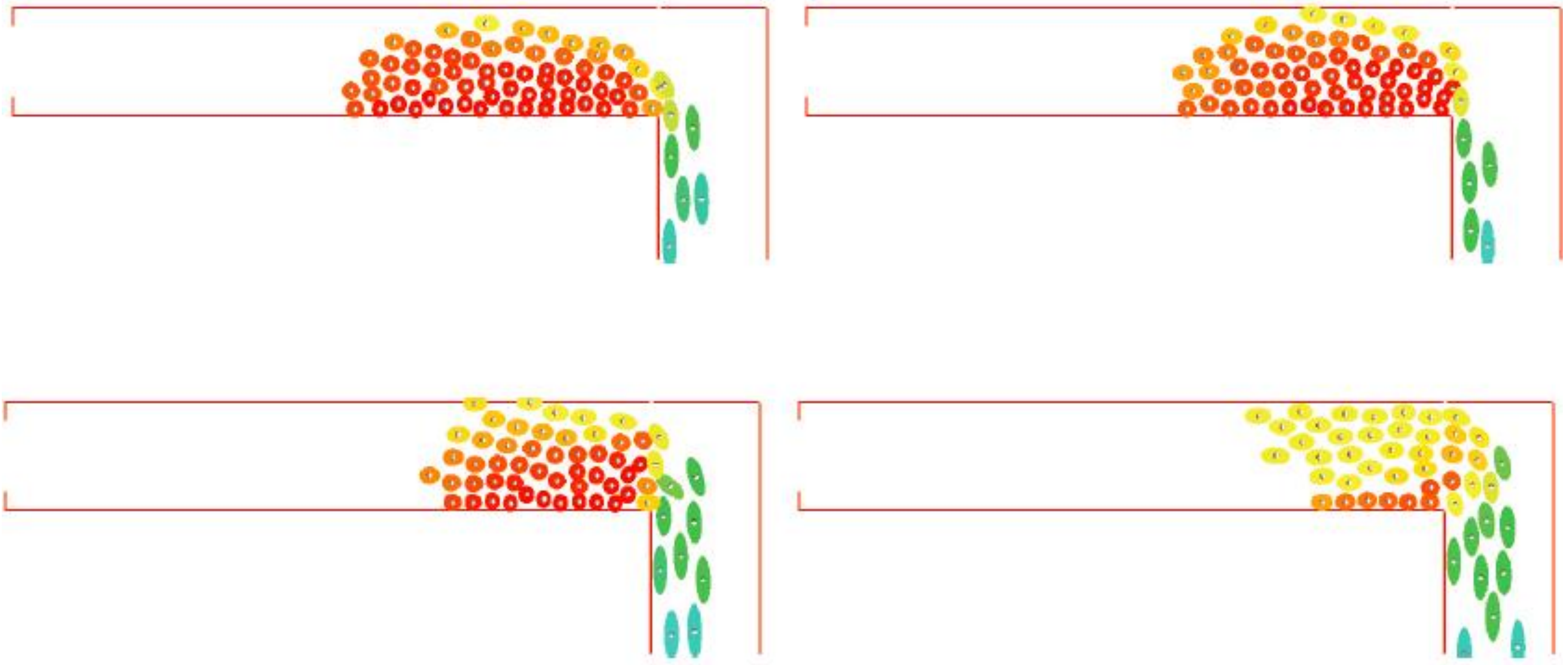
Density-dependent Direction (~FF Model)



$$l^i(t+\Delta t) = l^i(t) \cdot \Big(1 - p_d^i(t)\Big)$$

$$p_d^i(t) = \exp\left(-k_d \cdot \mathrm{occ}^i_{\mathrm{rel}}(t)\right)$$

Density-dependent Direction (~FF Model)



Conclusions

- Force-based models produce more problems than they solve

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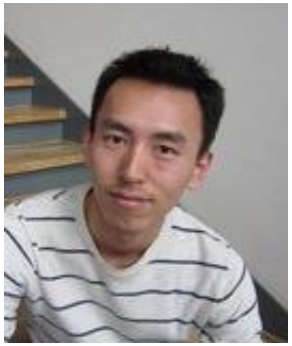
- Less is more

Conclusions

- Force-based models produce more problems than they solve
- Less is more
- First-order (rule-based) models are maybe more appropriate to adequately reproduce pedestrian dynamics
  - Robotics
- Cooperation (non egoist) steering through bottlenecks.

Acknowledgment

physicists



engineers

Thank you for your attention!

Comparison of different shapes